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RESEARCH PAPER

Climatic Drivers of Revegetation Management Practices in Australia: Analysis of a Social Survey

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Abstract Investment in small and large-scale revegetation in Australia is growing in response to concerns regarding the sustainability and productivity of agricultural landscapes. Site preparation and management—such as soil cultivation, weed control, fertilising, mulching, use of treeguards and watering—are major costs associated with small-scale revegetation. The aim of this study has been to investigate local revegetation knowledge and practices to determine the usefulness of each management practice for achieving success and to determine whether some practices are more suited to particular climatic zones. A national online revegetation survey was conducted to ascertain current small-scale revegetation practices and the factors that drive these choices. Management practices were found to be strongly associated with climate. Mulch, fertiliser, weed control and watering were applied more frequently in higher rainfall and higher temperature zones. Soil cultivation and treeguards were used more frequently in lower rainfall and lower temperature zones. These findings suggest that there may be some benefit in modifying existing revegetation guidelines to reflect climatic zones and management flexibility.

Keywords Local knowledge · Site preparation · Current practice · Climate

Introduction

In Australasia, investment in revegetation has accelerated in recent decades, driven by environmental and productivity concerns regarding the loss of native vegetation (Prinsley 1992; Potter and Lee 1998; Andrews 2000; Bennett et al. 2000; Schirmer 2007). This trend reflects growth of both large-scale commercial plantations

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(Barlow and Cocklin 2003) and small-scale private forestry (Harrison et al. 2002). The focus of this paper is on small-scale forestry, due to the challenge it faces of lack of economies of scale (as noted by Farrelly 2006).

One of the major expenses associated with revegetation is site preparation and management (Temple and Bungey 1980; Schirmer and Field 2000), such as weed control (both pre- and post-planting), soil cultivation, fertilising, guarding, mulching and watering. These practices, referred to here under the general heading of ‘management practices’, can generate favourable conditions for plant survival and growth. In particular, they can facilitate higher soil moisture, allow vigorous root development, reduce competition (Schönau et al. 1981), and improve the micro-climate around the plant (Russell 1995). Each of these management practices is addressed in this paper.

There is an expanding body of scientific literature investigating the effectiveness of various management practices on the survival and growth of a range of species. These studies indicate that the benefits of using management practices depend on the timing and method used as well as site and species characteristics (Graham et al. 2008). Recommendations from the scientific literature can only be extrapolated to a limited extent, because many studies are conducted on a small number of sites located in a limited number of agroecological zones (Prinsley 1992). To complement this growing body of scientific literature, this research involved a national survey of revegetation activities in order to compare across regions and identify general trends in revegetation practice.

Local knowledge is the wisdom accumulated by local people derived from their direct interaction with the environment (Altieri 1990). It is dynamic and responds to climate and land-use changes (Millar and Curtis 1999; Barrios and Trejo 2003). In Australia, a small number of studies have documented local knowledge regarding revegetation (Bennett et al. 2000). These have focused mainly on the reasons why revegetation is or is not carried out (Prinsley 1991; Wilson et al. 1995; Harrison and Herbohn 2005; Measham 2007), the costs associated with revegetation (Wilson et al. 1995; Schirmer and Field 2000), the benefits of revegetation (Wilson et al. 1995; Measham 2007), and the reasons why revegetation may or may not be successful (Prinsley 1991). While detailed information on the practices of a small number of individuals has been documented (Jones 1997; Andrews 2000; Close and Davidson 2003), none of the larger-scale studies have documented the management practices used by revegetation practitioners, or explored the perceived benefits of using such practices. Documenting this information would enhance the transfer of knowledge and could help emerging forest industries and conservation groups identify the best establishment methods for their area.

A project was initiated by the Commonwealth Scientific and Industrial Research Organisation to document the use of revegetation management practices in southern New South Wales (NSW), Australia. The first phase of the project involved using phone interviews to document the practices of 41 landholders, revegetation advisors and nurseries across five catchments, spanning an area of approximately 325,000 km^2 (as reported by Graham 2006). That study indicated that there are broad consistencies across catchments regarding the use of pre-planting weed control, post-planting weed control and soil cultivation; however, the use of other

practices including fertilising, mulching, guarding and watering was much less consistent. Due to the small sample it was difficult to determine the drivers of specific practices and whether site characteristics, particularly climate, affected the practices used. It was therefore decided to expand the study by conducting an online survey on local revegetation practices across Australia.

The main aim of the survey was to provide an overview of current seedling establishment practice. Specifically, the objectives were to: document and compare seedling planting practices across Australia; document perceptions regarding the potential drivers of successful establishment; and explore the influence of climate on choice of management practice.

Research Method

The Online Survey

The use of an online questionnaire allowed hundreds of revegetation practitioners to be surveyed throughout Australia. The first question asked respondents to identify how much effort (as defined by the respondent) they have invested in three types of revegetation activities, namely seedling planting, direct seeding and natural regeneration.[1] The questionnaire then continued in two parts. The first dealt with seedling planting and the second with direct seeding, because practices differ between these two forms of active revegetation. Respondents were asked to choose which part they preferred to answer. This article focuses on the responses to the seedling survey.

A pilot survey was conducted to assess the necessity, reliability and validity of questions. Feedback from the pilot survey indicated that the questions were clear; however, the options available for answering some questions needed revising. This feedback was incorporated prior to administering the questionnaire.

The final questions were designed to collect information on:

- *Planting histories*: years experience with planting, number of seedlings planted or area planted and mean planting density (stems/hectare). Respondents were also asked to identify their reasons for planting seedlings by ranking up to 11 reasons, based on those identified in previous studies (e.g. Measham 2005).
- *Species selection*: including proportion of local species planted, definition of local species, whether frost and drought tolerance were considered in deciding which species to plant, as well as the mean proportions of trees, shrubs and grasses planted.
- *Management practices*: whether soil cultivation, pre-planting weed control, installing treeguards, fertilising, mulching, watering and post-planting weed

[1] Corr (2003) defined the three main types of revegetation used in Australia as follows. Seedling planting involves the planting of nursery-grown seedlings either by mechanical or hand methods. Direct seeding involves sowing of seeds directly into the soil using mechanical or hand methods. Natural regeneration involves the germination of seedlings from seed fall from existing or nearby vegetation or brought in by birds or animals.

control were always, sometimes or never conducted. For those practices that were always or sometimes used, further information was sought on the particular methods used and in the case of pre-planting weed control, soil cultivation and post-planting weed control, the time at which they were conducted.

- *Definitions of planting success*: whether growth performance, survival or some other measure was used to assess the success of plantings. If growth performance was used then further information was sought on how successful growth was defined. If survival was used then further information was sought on the survival rate considered to represent success and the time after planting at which success was evaluated.
- *Factors which drive success*: respondents were asked to rank, in order of importance, 13 factors which influence the success of seedling establishment, based on those identified in previous surveys (notably that of Prinsley 1991).
- *Climatic zone*: respondents were asked to identify the nearest towns to the property or properties where they had conducted revegetation.

A three-pronged approach was used to distribute information about the survey to encourage participation. First, details about the survey were posted on two organisations' websites, one non-governmental (Greening Australia—http://www.greeningaustralia.org.au) and one governmental (Commonwealth of Australia Department of Agriculture, Fisheries and Forestry—http://www.daff.gov.au). Second, details about the survey were distributed through email bulletins of three organisations, both non-governmental (Greening Australia's Exchange eBulletin and Tweed Brunswick Landcare News) and governmental (Murray-Darling Basin Commission E-letter—http://www.mdbc.gov.au). Third, a snowballing approach was used. Thirty-seven revegetation advisors across Australia were contacted by phone to ask if they could help distribute information about the survey via their revegetation email lists.

In total 415 responses were received, with 367 responses to the survey on seedling planting and 48 to the survey on direct seeding. The majority of respondents came from New South Wales and Victoria (Fig. 1). Due to the small number of responses from the Australian Capital Territory (ACT), and its location within NSW, figures from the ACT have been amalgamated with those of NSW.

Obtaining Climate Data

Once the survey data had been compiled in a Microsoft Access database, the latitudes and longitudes for the towns closest to where the respondents had undertaken their revegetation were obtained from Geoscience Australia's 1:250,000 database of minor and major cities (http://www.ga.gov.au). Latitudes and longitudes were available for 208 of 237 towns identified by participants of the seedling planting survey. Elevation data were then obtained for these locations from Geoscience Australia's 9 s (250 m cell size) digital elevation model. This information was used to extract long-term mean rainfall and temperature data for each location using ANUCLIM Version 4.11 (Houlder et al. 2000). For the 41 respondents who did not provide location information, or for whom climate data could not be sourced

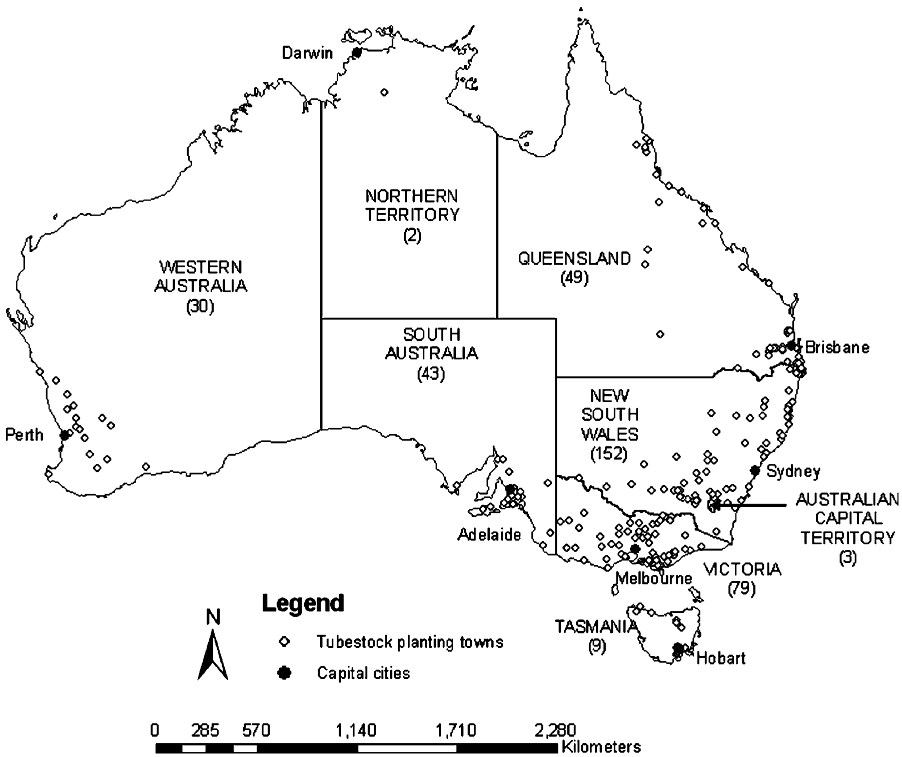

Fig. 1 Geographical distribution of respondents who answered the questionnaire on seedling planting. The number in brackets indicates the number of respondents who answered in each State

using ANUCLIM, listwise deletion was used to address missing values in the statistical analysis described below.

Definition of Variables and Statistical Analysis

The relationship between each of the response variables—management practices which respondents used in seedling planting in Australia—and a range of potential explanatory variables, listed in Table 1, were explored using generalized linear regression models (as described by McCullagh and Nelder 1989). The three level categorical response variables were converted to two level, or binary, categorical variables by combining the levels 'always' and 'sometimes' into a 'used' category, to contrast with the 'never' or 'not used', category. The binary response variables were modelled assuming a binomial error distribution and using a logit link function (McCullagh and Nelder 1989). The list of potential explanatory variables was derived from comments made during phone interviews with landholders, revegetation advisors and nurseries across southern NSW (reported by Graham 2006). Note that the management practice response variables were also included in the model building procedure as three-level categorical, explanatory variables. Model development and statistical significance testing adopted forward stepwise selection

Table 1 Possible explanatory variables available for inclusion in models developed to predict use of management practices in seedling planting across Australia

Variable	Type	Range or number of levels
Use of soil cultivation	Categorical	3
Use of pre-planting weed control	Categorical	3
Use of fertiliser	Categorical	3
Use of mulch	Categorical	3
Use of treeguards	Categorical	3
Application of water	Categorical	3
Use of post-planting weed control	Categorical	3
State or territory where planting takes place[a]	Categorical	7
Consideration of drought tolerance in species selection	Categorical	2
Consideration of frost tolerance in species selection	Categorical	2
Mean annual rainfall (mm)	Continuous	264–2472
Mean annual raindays	Continuous	48.8–214.5
Mean annual temperature (°C)	Continuous	10.8–26.8
Mean annual minimum temperature (°C)	Continuous	4.3–20.4
Mean annual maximum temperature (°C)	Continuous	15.1–34.0
Altitude (m)	Continuous	0–1297.2
Years revegetation experience	Continuous	0.5–40
Definition of revegetation success	Continuous	0.2–1
Mean planting density (stems/ha)	Continuous	1–62500
Proportion of trees planted	Continuous	0–1
Proportion of shrubs planted	Continuous	0–1
Proportion of grasses planted	Continuous	0–0.9

[a] Participants from the ACT were included with those from NSW

and assumed that the change in deviance was distributed as a chi-square statistic (following the method of Nicholls 1989). Statistical significance was taken to be at the 5% level of significance.

To explore further the relationship between management practices and mean annual rainfall and mean annual minimum temperature, multinomial logistic regressions (McCullagh and Nelder 1989) were fitted using the original three-level categorical response variables. The major advantage of using multinomial models in this context is that the sum of the predicted probabilities for a response being in one of the three categories is constrained to be one. Mean annual rainfall and mean annual minimum temperature were selected because they had had significant relationships with six of the seven management practices in the first pass of the logistic regressions.

Survey Results

There was considerable variation in respondents' revegetation practices and allocation of planting effort. Respondents of the seedling survey invested between

1 and 100% of their revegetation effort into seedling planting, between 0 and 65% into direct seeding and between 0 and 98% into natural regeneration (Fig. 2). The term ‘revegetation effort’ was not defined in the survey, allowing subjective interpretation of the term by respondents.

Respondents had between 6 months and 40 years experience with seedling planting (Table 1). The proportion of trees and shrubs planted varied from 0 to 100% and the proportion of grasses planted varied from 0 to 90%. The density of plantings varied from 1 to 62,500 stems/ha. The only practice that was reasonably consistently used across Australia was pre-planting weed control, with 95% of seedling planters always or sometimes employing the practice (Fig. 3). There was considerable variation in application of the remaining management practices across Australia.

Most seedling planters (74%) believed that survival within one year of planting is a key variable that could be used to determine the success of a planting. On average, the survival rate considered to determine a successful planting was 76%, but this rate ranged from 20% to 100%.

Species choice was ranked as the greatest influence (of 13 factors) on the success of plantings, being nominated by one-third of the respondents (Fig. 4). This was double the number who ranked soil moisture first, the variable ranked next highest. No respondent identified aspect as being the most important factor.

Findings from the Regression Analysis

The results of the forward stepwise regression modelling are presented in Table 2. In this table, a negative parameter estimate represents a negative relationship between the management practice and the explanatory variable. Taking soil cultivation as an example, Table 2 shows that the likelihood of soil cultivation decreased as mean annual rainfall, mean annual raindays, consideration of drought tolerance and the proportion of grasses planted increased. There were also

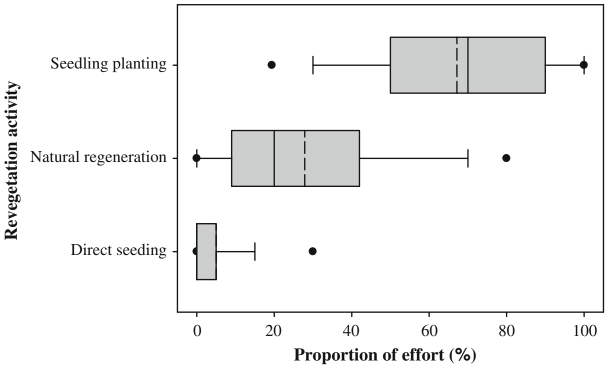

Fig. 2 Amount of effort invested in three revegetation activities. The boundary of the box closest to zero indicates the 25th percentile, the solid line within the box marks the median, the dashed line marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers above and below a box indicate the 10th and 90th percentiles. Dots indicate 5th and 95th percentiles

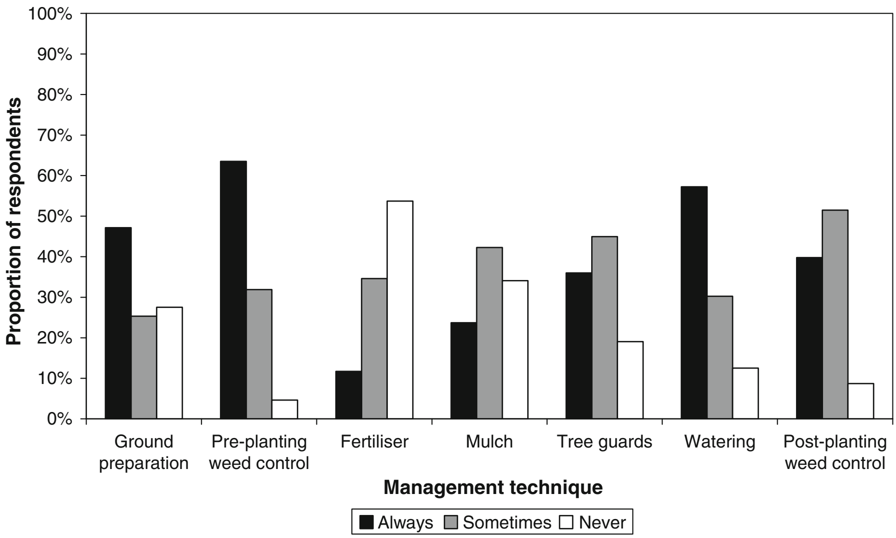

Fig. 3 Use of management practices by seedling planters across Australia

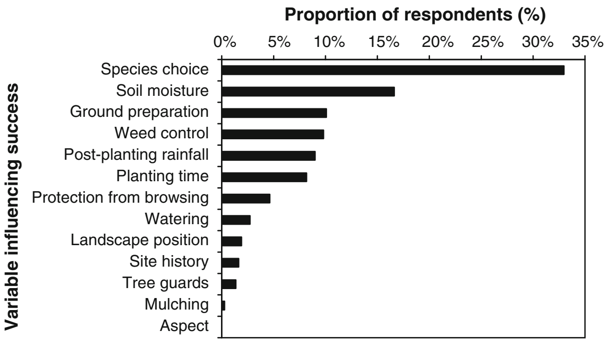

Fig. 4 Proportion of respondents that ranked each variable as the most important factor influencing the success of plantings

significant differences between the States with regards to the use of soil cultivation. This effect appears to be driven by the much lower use of soil cultivation by the South Australian respondents, with 58.1% of respondents from this State never using soil cultivation. There were no significant differences in the use of soil cultivation between respondents in the four remaining States and the Northern Territory and New South Wales (the reference group). The maximum proportion of respondents, from the remaining States and the Northern Territory, who never used soil cultivation was 29.1%, for Victoria.

The frequency of use of pre-planting weed control increased with higher expectations of success, and decreased with occasional or non-use of mulch. Use of pre-planting weed control was significantly lower when post-planting weed control was never undertaken. There were no significant differences in the use of pre-

Table 2 Coefficients and standard errors for binomial models fitted for each of the management practices[a]

Variable	Use of soil cultivation		Use of pre-planting weed control		Use of mulch		Use of fertiliser		Use of treeguards		Use of watering		Use of post-planting weed control	
	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.
Constant	4.752	0.85	8.2	17.3	1.228	0.84	−2.09	1.02	6.51	1.17	5.29	1.06	1.78	1.06
Mean annual rainfall	−0.0011	0.0005			0.0042	0.0010	0.0012	0.0004					0.0017	0.0008
Mean annual raindays	−0.0146	0.0086			−0.0243	0.0101								
Mean annual temperature									−0.2771	0.0589				
Mean annual max temperature							0.0885	0.0428						
State 2 (Northern Territory)	4.0	13.7												
State 3 (Queensland)	−0.101	0.441												
State 4 (South Australia)	−2.03	0.569												
State 5 (Victoria)	−0.384	0.521												
State 6 (Western Australia)	1.64	1.17												
State 7 (Tasmania)	0.966	0.994												
Use of pre-planting weed control 2					0.858	0.37								
Use of pre-planting weed control 3					−3.32	1.1								
Use of mulch 2			−6.9	17.3			−0.935	0.357	0.285	0.428	−1.98	1.07	−0.156	0.838
Use of mulch 3			−8.8	17.3			−1.754	0.403	−1.005	0.479	−3.65	1.03	−1.323	0.81

Table 2 continued

Variable	Use of soil cultivation		Use of pre-planting weed control		Use of mulch		Use of fertiliser		Use of treeguards		Use of watering		Use of post-planting weed control	
	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.	Parameter estimate	s.e.
Use of treeguards 2					0.082	0.376					−0.225	0.465		
Use of treeguards 3					−1.766	0.532					−1.924	0.448		
Application of water 2					−1.379	0.365			0.461	0.41				
Application of water 3					−2.247	0.53			−1.663	0.443				
Use of post-planting weed control 2			0.044	0.732										
Use of post-planting weed control 3			−1.88	0.759										
Proportion of grasses planted	−3.48	1.06			3.3	1.38								
Consideration of drought tolerance	−0.938	0.348												
Definition of success			4.31	1.67										

[a] These variables have been selected using forward stepwise regression. Numbers 2 and 3 next to a management practice indicate occasional use and non-use of the practice, respectively

planting weed control between those respondents who always and sometimes used post-planting weed control. The large standard errors in the model for pre-planting weed control result from the high proportion of respondents who always use this practice (Fig. 3).

Mulch use increased with mean annual rainfall and the proportion of grasses planted. Use of mulch decreased with occasional or non-use of watering and non-use of treeguards. The seventh pass of the forward stepwise procedure indicated that there were differences between the States with regards to mulch use. This effect appears to be driven by the distinctive use of mulch by the 11 Tasmanian and Northern Territory respondents, compared to respondents from the other States. Due to the small number of respondents from Tasmania and the Northern Territory, the variable 'State' was removed from the final model for mulch.

Fertiliser use significantly increased with mean annual rainfall and mean annual maximum temperature and decreased with occasional or non-use of mulch. Treeguard use decreased with mean annual temperature and non-use of mulch and watering. There were no significant differences in the use of treeguards between respondents who always and sometimes used mulch or watering. Use of watering decreased with non-use of mulch and treeguards. There were no significant differences in the application of water between those respondents who always and sometimes used mulch or treeguards. The likelihood of using post-planting weed control increased with mean annual rainfall and decreased with non-use of mulch.

Findings from the Multinomial Analyses

The results of the multinomial analyses for each of the seven management practices against mean annual rainfall and mean annual minimum temperature are presented in Figs. 5 and 6, respectively. Use of treeguards is not included in Fig. 5 and use of pre-planting weed control is not included in Fig. 6, because the multinomial models of these practices against rainfall and minimum temperatures, respectively, were not significant. Symbols, rather than lines, are used in the graphs to reflect the concentration of respondents with respect to mean annual rainfall and minimum temperature.

With the exception of soil cultivation, the estimated probability of always conducting each of the practices increased as mean annual rainfall increased. The probability of always conducting soil cultivation decreased as rainfall increased. The probability of never conducting each of the practices, with the exception of soil cultivation, decreased as rainfall increased. The graph also indicates that the probability of never using a practice was highest for application of mulch (Fig. 5a) and fertiliser (Fig. 5b) and lowest for pre- and post-planting weed control (Figs. 5f and d, respectively) as well as for watering (Fig. 5e).

There was a less distinct pattern for occasional use of the practices. For mulch and fertiliser, as mean annual rainfall increased to 1000 mm and 1500 mm, occasional use increased, resembling the pattern for consistent use. As rainfall increased beyond these amounts, occasional use of both practices decreased, reflecting the pattern for non-use. For pre- and post-planting weed control as well as

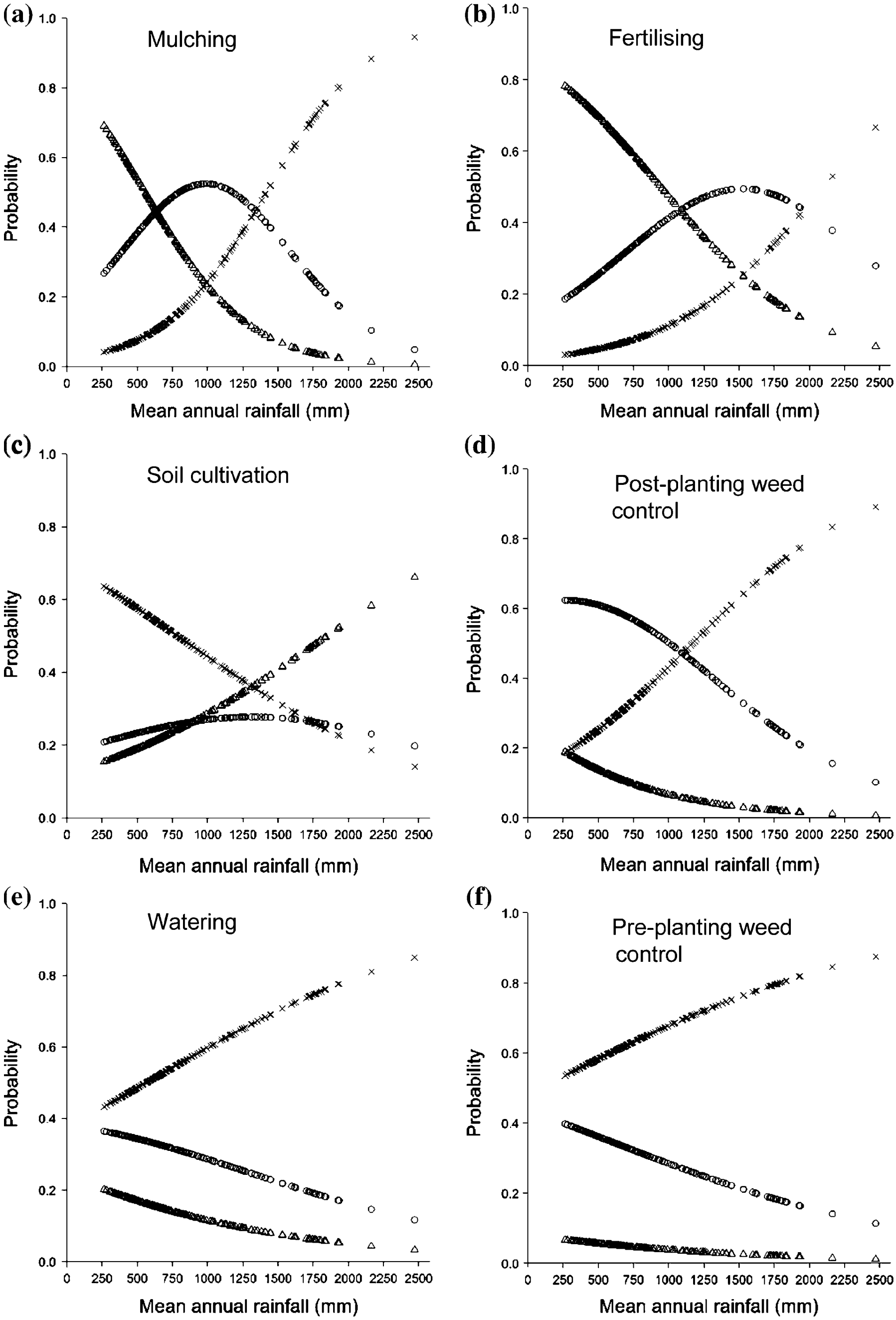

Fig. 5 Results of the multinomial analysis of six of the seven management practices with mean annual rainfall as the explanatory variable. These figures indicate the estimated probabilities that a respondent will always (×), sometimes (○) or never (△) use each management practice

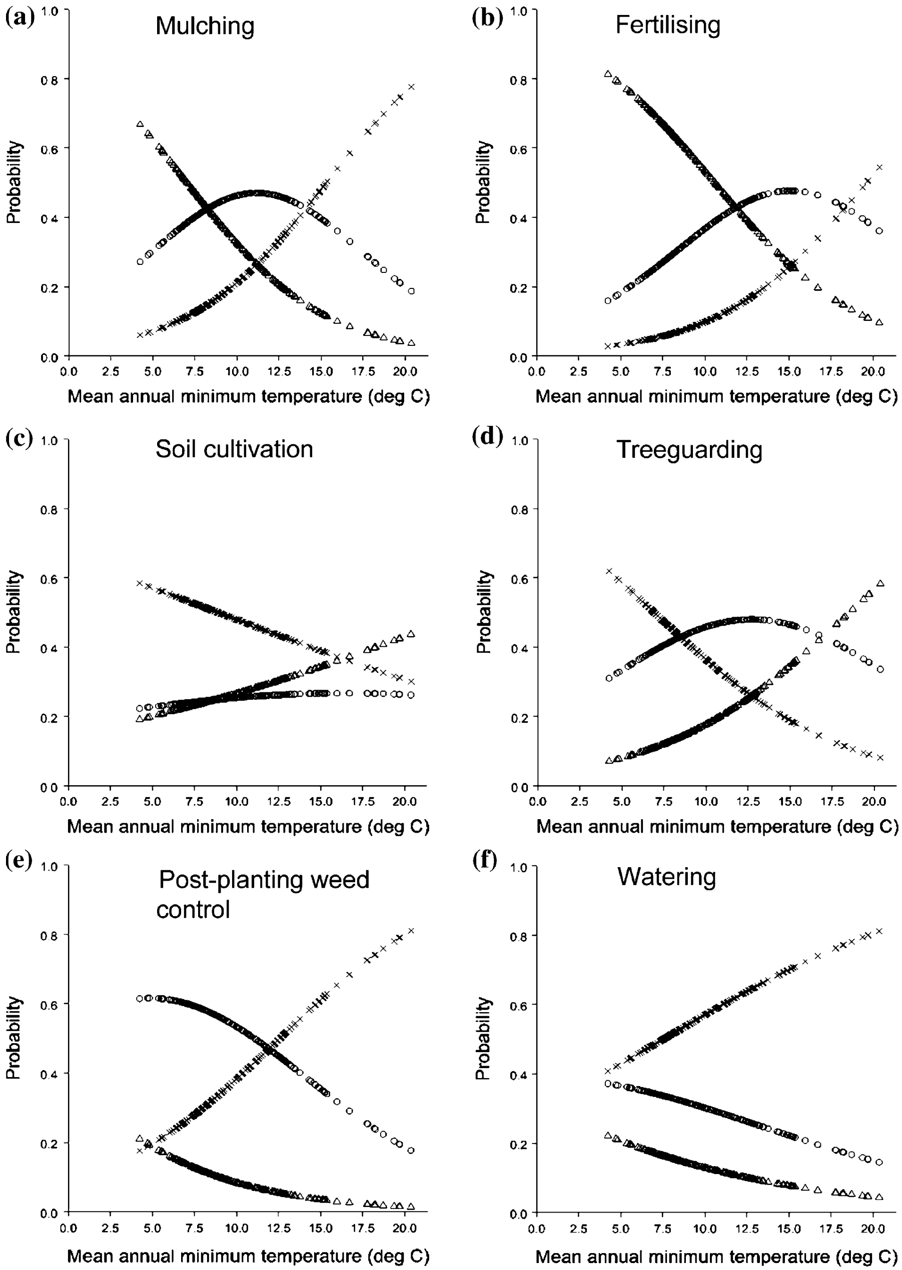

Fig. 6 Results of the multinomial analysis of six of the seven management practices with mean annual minimum temperature as the explanatory variable. These figures indicate the estimated probabilities that a respondent will always (×), sometimes (○) or never (△) use each management practice

watering, occasional use was highest in the semi-arid zone (mean annual rainfall between 250 and 500 mm). As mean annual rainfall increased beyond 500 mm occasional use of these practices decreased, reflecting the patterns for non-use of these practices. For soil cultivation, occasional use followed a near constant probability (of about 20%) regardless of rainfall.

The patterns of estimated probabilities for each management practice against mean annual minimum temperature (Fig. 6) are similar to the patterns for each management practice against mean annual rainfall (Fig. 5). Where probabilities of a practice always being used increased with increasing rainfall—which was the case for mulching, fertilising, post-planting weed control and watering—these probabilities also increased with increasing minimum temperatures (Fig. 6a, b, e and f). For treeguard use, which was not related to rainfall, increasing temperature was associated with increasing probabilities of never using treeguards (Fig. 6d). Greatest use of treeguards occurred at locations with low mean annual minimum temperatures. Occasional use of treeguards increased as mean annual minimum temperatures increased to approximately 12.5°C, and then decreased for higher temperatures.

Discussion

The survey findings reveal that use of particular management practices was strongly associated with climatic variables and use of other management practices. The State in which seedling planting was carried out, the proportion of grasses planted, consideration of drought tolerance and the definition of a successful planting was moderately associated with management practices, as each variable was present in only one or two of the final binomial models. Years of experience, altitude, planting density, consideration of frost tolerance and the proportion of trees and shrubs planted appeared to have little explanatory power, in that they were not present in any of the final binomial models. In the discussion that follows each management practice is examined individually to understand its potential drivers before a synthesis of the overarching trends is presented.

Examining the Use of Soil Cultivation

Soil cultivation is less likely as rainfall increases (Table 2). The multinomial analysis provides additional information on this trend, indicating that consistent use of soil cultivation decreased with increasing rainfall but occasional use was almost constant across all rainfall zones. The most common form of soil cultivation used by respondents was ripping, being used by 74.4% of respondents who always or sometimes used soil cultivation. One of the main reasons for ripping, identified in both the scientific literature and practical revegetation guidelines, is to increase the available soil moisture (Perry 2004; Harper et al. 2008). In lower rainfall areas, there may be a perception that there is insufficient soil moisture, indicated by the greater emphasis on selecting drought tolerant seedlings (Table 2). Such a perception could explain why consistent use of ripping was higher in these areas.

The pattern of occasional use of soil cultivation may reflect the benefit of ripping for facilitating root growth (Harper et al. 2008), which would be beneficial regardless of rainfall.

Use of soil cultivation was significantly lower in South Australia than in the other States. There are a number of possible reasons for this. First, in South Australia there was a higher concentration of plantings within and around urban areas (Fig. 1). These plantings are likely to be smaller and less amenable to the use of large machinery, reducing the likelihood that soil cultivation is conducted (Graham 2006). Second, organisations that support revegetation activity in Australia often have State-based structures, e.g., Greening Australia and Landcare (http://www.landcareonline.com). These State-based divisions are likely to drive the formation of information networks. At a local scale, Jones (1997) and Bauer et al. (2003) have shown that management practices and uptake of technology are affected by personal networks. Therefore, networks formed around State-based structures may influence the flow of information and uptake of practices within that State. In South Australia, information on management practices, including soil cultivation, may have been slow to reach practitioners because this State was the last State to run a Master TreeGrower course (a national farm forestry and outreach education program), lagging two to six years behind the other states (Black et al. 2000; Reid and Stephen 2007). By 2004, South Australia had only conducted one Master TreeGrower course, while other States had conducted up to 22 courses (Reid and Stephen 2007).

Soil cultivation was also related to the proportion of grasses planted, with the use of soil cultivation decreasing as the proportion of grasses planted increased. This may possibly be because the establishment of grasses reflects a motivation to not disturb the soil. For example, in native grasslands and grassy woodlands revegetation guidelines recommend a minimal disturbance approach (e.g. Corr 2003).

Examining the Use of Pre-Planting Weed Control

Those practitioners that had high expectations of success were more likely to have used pre-planting weed control. However, only 9.8% of respondents identified pre-planting weed control as being the most important factor driving success (Fig. 4). This agrees with the findings presented in Measham (2005), where only 12.2% of respondents identified weeds as a factor affecting success. In contrast, Prinsely (1991) found that farmers believed weed competition to be the main cause of establishment failure. Since 1991, weed control may have become so much a part of the culture of revegetation practice, being always or sometimes used by 95% of respondents (Fig. 3), that respondents who use this practice have come to expect a higher level of success. Having mastered this practice, they may now be planning to address other factors that affect success, such as those which Prinsley (1991) found to be ranked much lower 17 years ago. For example, Prinsley (1991) found that species choice was the ninth most commonly cited reason for planting failure. In the present study, species choice was the highest ranking factor (Fig. 4). This agrees with the findings of Measham (2005), where species choice was the most common factor that respondents would change if planting again in future.

Use of pre-planting weed control was also found to increase with use of mulch and post-planting weed control. This could suggest an all-or-nothing approach to weed control, where planters who believe pre-planting weed control is important also believe that post-planting weed control and mulching is important. Alternatively, rainfall could be driving the joint use of these three weed control practices. Although rainfall was not selected in the final model for pre-planting weed control, a significant relationship was found in the first pass of the regression analysis as well as in the multinomial analysis. The multinomial analysis indicates that the probability of always using pre-planting weed control increased with increasing rainfall, as did probability of post-planting weed control and mulch application. In that higher rainfall results in increased weed growth, rainfall could be the underlying driver of support for weed control.

Examining the Use of Fertiliser

Fertiliser use increased with both temperature and rainfall. This corresponds well with the fact that fertiliser is known to have the greatest impact under higher soil moisture and temperature conditions (as demonstrated by Goncalves and Carlyle 1994). Current revegetation practices reflect this knowledge, with planters in areas with low rainfall and temperature being less likely to use fertiliser than those in higher rainfall and temperature zones. This congruence between local and scientific knowledge may be coincidental, reflecting the results of respondents' own experimentation, in isolation of scientific findings. Alternatively, it may represent an overlap of scientific and local knowledge. For example, Vanclay (2004) argued that farmers use scientific knowledge when it fits with their own understanding.

Fertiliser use was also related to mulch use, with use of mulch resulting in higher use of fertiliser. There are at least three explanations for this pattern. First, mulching leads to greater soil moisture retention (Walker and McLaughlin 1989), which could aid the uptake of fertiliser. Second, mulch acts as a form of weed control (Temple and Bungey 1980; George and Brennan 2002), and therefore any additional weed competition, stimulated by applying fertiliser (Adams et al. 2003; Mercuri et al. 2005), would be controlled by the mulch. Third, some landholders and revegetation advisors believe the costs of applying mulch and fertiliser outweigh their benefits (Graham 2006). It is therefore likely that the use of these practices reflect economic considerations.

Examining the Use of Mulch

The binomial and multinomial analyses indicate that higher mean annual rainfall increases the probability that mulch is used. This suggests that the main reason why mulch is used is to control weeds rather than for retention of soil moisture. If mulch were to be used for soil moisture retention it would be more likely to be used in low rainfall areas, which was not found to be the case.

Mulch use was also related to the use of treeguards and watering, with those who never used guards or watered being less likely to use mulch. Jones (1997) documented a similar pattern on the New England tablelands. At seven of eight sites

where mulch was not used, treeguards and watering were also not used. All three practices are labour-intensive (Schirmer and Field 2000) and are often considered too expensive for wide-scale applications (McDonald et al. 1994). It is therefore likely that the use of these practices reflects either the small size of the plantings or greater commitment to more labour-intensive practices.

As for soil cultivation, the proportion of grasses planted was associated with mulch use. In this instance, mulch use increased with an increasing proportion of grasses. A possible explanation for this is that planting grasses requires greater effort than planting shrubs or trees, which fits with the more labour-intensive planting philosophy associated with mulch use.

Examining the Use of Treeguards

Treeguards were the only management practice which did not have a significant relationship with rainfall in the first pass of the binomial model. However, treeguard use was found to have a significant relationship with all three temperature variables in the first pass of the regression modelling, with mean annual temperature included as a statistically significant explanatory variable in the final model. The most common type of treeguard used by respondents was plastic, being used by 66.3% of respondents who always or sometimes used treeguards. Plastic treeguards are known to change the microclimate around plants, increasing temperature and humidity (Russell 1995). It appears that current revegetation practices reflect this knowledge, with planters in low temperature areas being more likely to use guards than those in higher temperature areas (Fig. 6).

Use of treeguards was also related to the use of mulch and watering, with planters who did not mulch or water being less likely to use treeguards. This adds weight to the proposition of an all-or-nothing approach to the use of more labour-intensive management practices discussed above.

Examining the Use of Watering

The likelihood of watering every planting increased as mean annual rainfall increased. While this result appears counter-intuitive, one explanation is the greater availability of water in these regions or the greater need to water local-provenance seedlings. While it could be expected that more drought sensitive species are planted in high rainfall areas, it is unlikely that this is driving watering in these regions. Consideration of the drought tolerance of seedlings was not found to have a significant relationship with application of water in the first and consequent passes of the binomial model development.

Watering was also associated with the use of mulch and treeguards, with non-use of both practices resulting in lower probabilities of applying water. These findings agree with observations made by Jones (1997), who found that in all sites where water had been applied (i.e. nine of 52 sites), mulch and guards were also used. This further suggests that the application of mulch, treeguards and water are strongly interrelated.

Examining the Use of Post-Planting Weed Control

Use of post-planting weed control increased with rainfall and is likely to be associated with the trend noted by Singh et al. (1996) that more intense weed growth occurs in wetter areas. Likelihood of using post-planting weed control also increased with the use of mulch. As mentioned for pre-planting weed control, this appears to reflect an intensive weed control philosophy towards seedling planting where a combination of pre- and post-planting weed control as well as mulch is used. Conversely, some planters do not perceive the need for weed control, particularly in lower rainfall areas, and therefore do not employ any weed control practices.

Synthesis of Strategies for Site Preparation and Management

Of the climatic variables, rainfall was found to have the strongest relationship with management practices. Mean annual rainfall was found to have a significant relationship with all variables, with the exception of treeguards, in the first pass of the forward stepwise procedure. Use of five management practices (namely pre- and post-planting weed control, mulching, fertilising and watering) increased with mean annual rainfall. Use of soil cultivation decreased with increasing rainfall and there was no effect of rainfall on the use of treeguards. The mean annual rainfall variable was also included in four of the seven final binomial models. Temperature had less of an effect on management practices. Temperature variables were included in only two of the final binomial models. Nevertheless, mean annual minimum temperature was found to have a significant relationship with six of the seven management practices in the multinomial models. The patterns for temperature parallel those for rainfall, with practices used in high rainfall areas also being used in high temperature areas.

The multinomial analyses of management practices against mean annual rainfall and minimum temperature showed that there was value in specifying three level response variables. For each practice, the 'sometimes' category showed a response distinct from the 'always' and 'never' categories. These findings suggest that there is some benefit in modifying existing revegetation guidelines to reflect the climatic zone and management flexibility. For example, the survey revealed that soil cultivation is almost always used in low rainfall and low temperature zones. Flexibility in the application of management practices is needed in the mid-range rainfall (i.e. 1000–1500 mm/year) and temperature (i.e. 12.5–15°C) zones, with use of particular practices adjusted to suit the local climate. In high rainfall zones, a suite of practices (including post-planting weed control, mulching and fertilising) was almost always perceived to be beneficial. Use of pre-planting weed control was high across all zones and increased as rainfall increased.

Clearly, revegetation guidelines should integrate both scientific and local knowledge. In a recent review of the scientific literature Graham et al. (2008) showed that early eucalypt survival can be maximised by using one or two management practices, and that there is little benefit of using additional practices. The two practices that consistently improved survival and growth were soil

cultivation and post-planting weed control. In light of the review by Graham et al. (2008) and the local practices documented here, soil cultivation is likely to be most beneficial in low rainfall zones and post-planting weed control is likely to be most beneficial in high rainfall zones. In moderate-rainfall zones use of both soil cultivation and post-planting weed control could be recommended.

Of the management practices, mulch use was most frequently related to use of other practices. The only practice for which mulch was not selected in the final binary model was soil cultivation. This suggests that use of mulch is a reliable indicator of the likelihood of using other practices and reflects underlying philosophies towards seedling planting. Planters who use mulch are likely to believe that weed control is important and that it is worth investing in more labour-intensive practices such as treeguards and watering.

Conclusion

Seedling planting practices tended to be highly diverse across the areas surveyed. This diversity is likely to be a result of site-based differences in climate, particularly rainfall and temperature, and varying management approaches, from labour-intensive to minimalist. By recognising these influences, future guidelines can be tailored better to meet the needs of new revegetation practitioners, depending on the climatic zone in which they live as well as the amount of effort and resources they wish to invest in seedling planting. With regard to climatic zone, the scientific literature and the local practices documented here indicate that soil cultivation is likely to be most beneficial in low rainfall zones. In moderate rainfall zones use of both soil cultivation and post-planting weed control could be recommended, and in high rainfall zones post-planting weed control appears warranted. Depending on the amount of effort that practitioners are willing to invest in planting seedlings, post-planting weed control could simply involve application of herbicides or, for those willing to invest more effort, this could also include the use of mulch. Regardless of climate or planting effort, local practice indicates that pre-planting weed control is considered necessary across Australia, because it was the most frequently used practice and was clearly associated with definitions of success.

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